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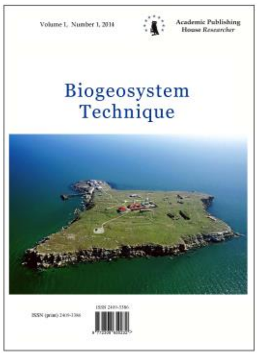

Monitoring Soil Salinity and Recent Advances in Mechanism of Salinity Tolerance in Plants

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Abstract

Salt stress is the most prominent factor that has affected agriculture production, induced various problems, and a serious challenge to food security. Numerous adverse effect can be noticed during salt stress that is pretentious to their physiological, biochemical, molecular, and morphological functions. Plants develop a mechanism to subdue the problem that arises through salt stress via adoption or tolerance process but these mechanisms are not sustainable. It leads to a decline in the biomass of plants and overall crop productivity. For sustainable development of food security and overcome the looming endanger of salt stress in the reduction of food production and exponential population growth, novel and advanced technologies like plant breeding, biotechnology, nanotechnology can be explored and made to work for the development of salt tolerance of crop varieties.

Keywords: Salt stress, food security, physiological, molecular, plant breeding, biotechnology, nanotechnology.

1. Introduction

The world population is expected to reach 9.6 billion by the year 2050 and approximately 83 million people are being added to the world's population every year (UNFPA, 2014). To feed

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such a huge population, about 44 million metric tons of food crops will have to be produced every year to meet the demands of the increased population by 9.6 billion by 2050. However, the expansion of arable land has been limited due to climate change and global warming (FAO, 2012; Miah et al., 2013), the climatic change affected plant physiological, biochemical, and molecular functions known Abiotic stress, affected plant called abiotic stressors. Out of all abiotic stresses, salinity and drought are the two main abiotic stresses that impede large-scale world crop production (Munns, 2011). Soil is the blood of the earth, if blood is affected by various types of diseases then the body is not fit, similarly, if earth blood that is soil is affected by various types of problems such as salinity, nutrition, etc. then it can not produce healthy crops.

Globally, about 53 % in Asia and Australia, 13 % in Latin America, 13 % in Near East, 10 % in Europe, 9 % in Africa, and 2 % in North America lands are salt-affected. More than 30 % of the world's total irrigated lands are used to produce food crops. On the other hand, an estimated 20 % or more of irrigated lands are high saline, and 50 % of irrigated land is affected by medium or secondary salinity (Munns, 2002, Ruan et al., 2010). Data from all these salt-affected lands show that the saline situation in the land increased every year due to poor agricultural practices and climate change. The present review, focus special attention to all the aspects of soil salinity monitoring, crop improvement approaches, and stress tolerance mechanism in plants.

2. Results and discussion

GIS remote sensing for monitoring soil salinity

Remote sensing is a fundamental process that helps in monitoring crop health through analyzed soil, weather, temperature, humidity, this analyzed study beneficial for crop production (Wu et al., 2015). The working principle of GIS remote sensing is recording and measuring some components like electromagnetic radiation which is reflected by the earth’s surface (Nezami et al., 2012). For monitoring the agricultural production GIS remote sensing are using several types of vegetation indices (VIs) tools like NDVI (Normalized Difference Vegetation), PVI (Perpendicular Vegetation Index), and SAVI (Soil Adjusted Vegetation Index) (Tucker et al., 1979; Rondeaux et al., 1996; Huete, 1988).

GIS remote sensing is useful for analysis of salty soil, salt-affected vegetation, saline water, pond water, and high water table area give a unique reflectance in comparison to other landscape features, for example, GIS remote sensing techniques are used to monitoring saline-sodic soil patches in the Machhlishahr of Jaunpur district of the Indian state of Uttar Pradesh, India (Figure 1).

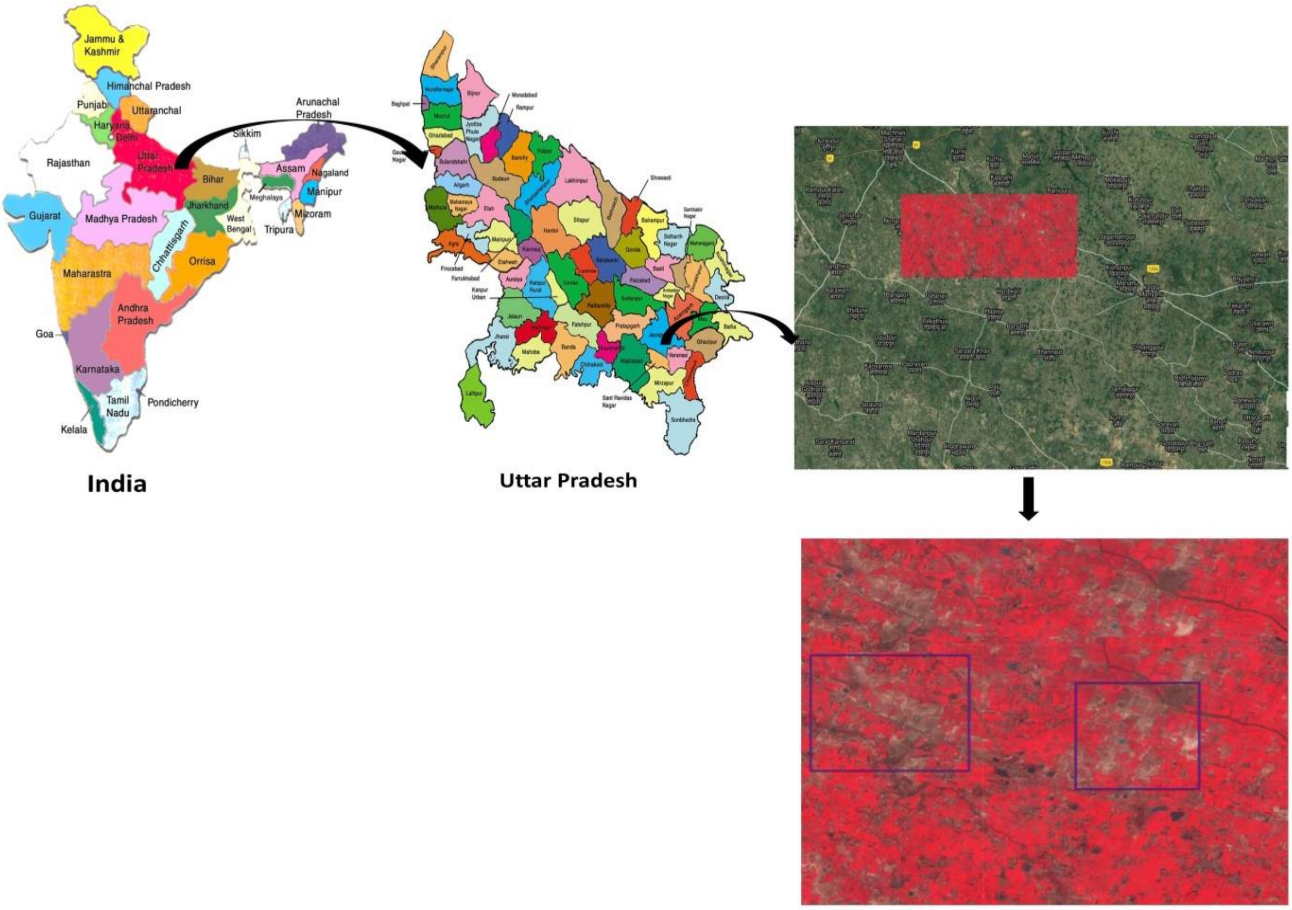

Fig. 1. GIS remote sensing monitoring of Saline-sodic soil land in the Machhlishahr of Jaunpur district of the Indian state of Uttar Pradesh, India

Remote sensing is an art of analysis which combined with science through it can elucidate the properties of the earth's surface by collecting the different types of earth surface data using various types of sensors. For the land survey, remote sensing techniques work on a range of wavelengths between 0.4 and 2.4 nm (Ojo, Ilunga, 2018). Salt patches present on terrain surface can be detected by remote sensing or directly on bare soils, with the help of salt efflorescence and crust. It can also be analyzed by the plants that are grown in a salt-affected area through GIS remote sensing base vegetation indices techniques (Mougenot et al., 1993). Regions in arid salt-affected land, the soil have a salt crust that is whitish in structure. White color have high reflectance that is easily being able to be detected by GIS remote sensing base vegetation indices.

Mechanism of plant responses and adaptation to soil salinity

Plants are divided into two classes based on their response to salt concentrations. In first-class comes "halophytes" plants: completed their life cycle in the salt environment thus they are native towards it. In the second class comes "glycophytes" plants: sensitive to a saline environment. At an above considerable concentration of salts glycophytes, plants are showing some physiological disorders like leaf discoloration, loss of biomass, and growth inhibition. Based on the growth response in salinity conditions. Halophytes and glycophytes are classified into the following groups:

Group I – In this group, those halophytes are come which continue to grow rapidly at 200-500 mM NaCI concentration (Greenway, Munns, 1980). Group I is further divided into Group I A and Group I B. In group IA which halophytes plants are come which continuously grown with Cl^- in 400 mM salt concentration, for example, *Suaeda maritime*, *Atriplex nummularia* (Greenway, Munns, 1980; Taiz, Zeiger, 2002). In group I B these halophytes are come which are salt tolerance but their growth is retarded, for example, *Atriplex hastata, Spartina townsendii*, and sugar beet (Greenway, Munns, 1980).

Group II – In group II halophytes plants are grow very slowly above than 200 mM NaCI concentration. Group II divided into following groups

(1) Tolerant: In this group salt tolerant halophytic monocotyledons without salt glands are come for example *Festuca rubra ssp. litoralis, Puccinellia peisonis*. Also some glycophytes or nonhalophytes also come under in this group like cotton and barley.

(2) Intermediate: Under this class, plants are come that partially affected by salt concentration, for example, tomato.

(3) Sensitive: In this group, plants are highly sensitive to salt concentration, for example, common beans and soybeans.

Group III – In this group glycophytes or non-halophytes come which are very salt-sensitive, even in low concentration of salt, for example, Fruit trees like citrus, avocado and stone fruit.

The primary response for the salinity level in the plant is slow growth rate of leaves (Kibria and Hoque, 2019) in salt stress shoot is much affected than root (Munns and Termaat, 1986), but when plant root is exposed to higher soil, salinity level then root growth is also effected (Koca et al., 2007; Tuna et al., 2008). Shabala, Babourina and Newman (2002) reported that due to salinity stress the new cell production rate reduced that inhibited the overall growth of plants. Due to alteration of plant cell wall structure induced by salinity stress, caused stiffness in cell wall which leads the reduction in dry weight of plant. Salinity stress in root zone is developed the osmotic stress, which caused disruption in cell ion homeostasis by inducing both the inhibition in uptake of essential nutrients like K^+ ions and increased accumulation of Na^+ and Cl^- ions (Paranychianakis and Chartzoulakis, 2005).

Under salt stress conditions, plants are increase the uptake of Na^+ ions that affected uptake of other ions like K^+ that leads to cause the K^+ deficiency resulting the lowering of K^+/Na^+ ratio (Kibria et al., 2017). Salt stress induced the significant changes in physiological and biochemical conditions in plant, for example. decrease in protein synthesis, lower level of leaf chlorophyll content, increased ROS accumulation, changes in antioxidant enzymatic activities, enhanced accumulation of compatible solutes such as proline, glycine betaine, sorbitol, mannitol, pinitol and sucrose (Figure 2) (Kibria, Hoque, 2019).

Effect of salinity on plant physiological and biochemical states

High salinity in soil effects plants at physio-biochemical and molecular levels by inducing oxidative stress, water stress, nutritional disorders, ion toxicity, alteration of metabolic processes, membrane disorganization, reduction in cell division and expansion, and genotoxicity (Carillo et al., 2011).

All these adverse physio-biochemical and molecular conditions simultaneously leads to inhibits plant growth, and its development (Table 1).

Table 1. Physio-biochmical effects of salt stress in plant

Physio-biochemical processes	**Salt induced damage and symptoms**	**References**
Photosynthesis	Salinity affects photosynthesis mainly through reduction in leaf area, chlorophyll content and stomatal conductance, and to lesser extent decrease in photosystem II efficiency	Netondo et al., 2004
Reproductive development	Salinity essentially affects plant reproductive development by inhabiting microsporogenesis and stamen filament elongation, which lead programmed cell death in some tissue. It also promote ovule abortion and senescence of fertilized embryos.	Shrivastava and kumar, 2014
Water transport	The initial stage of salt stress plants experiences water stress condition resulting in plant reduces leaf expansion.	Carillo et al., 2011

Osmotic regulation	Plants immediately experienced salt stress conditions cause osmotic stress. If plant continuous experience osmotic stress condition it inhibited cell expansion and cell division as well as stomatal closure.	Flowers, 2004, Munns, 2002
Ionic regulation	Long term exposure to salinity plant experience ionic stress, this ionic deregulation lead to premature senescence of adult leaves. Mature leaves also face senescence condition because of higher Na^+ accumulation which affected protein synthesis and enzymatic activity.	Cramer and Nowak, 1992; Carillo et al., 2011

Reduction of plant growth and development affected the production of grains, and to overcome this problem, research community use new tools and techniques for improvement of crops against the salinity stress but for this they required deep information related physiology, morphology, molecular and biochemical changes in plants due to salt strress.

Salinity effects on the physiological condition of plant

Salinity effects on plants photosynthesis and photosynthetic pigments

During salinity response, plants exhibits dramatic decrease in stomatal aperture number. Rajput et al. (2015) studied on stomatal density, area, and size of stomata opening that were highly affected by different salt concentrations, led to reduce evaporation. Quite a few studies also reveal that higher or moderate salinity level has affected the gas exchanges, decrease in photosynthetic rate, and these symptoms are completely analogous to drought stress (Bongi, Loreto, 1989; Loreto et al., 2003). Wang and Nil (2000) have reported that *Amaranthus tricolor* plants are adapted against salt stress conditions by deviating in its leaf growth and chemical composition, i.e., chlorophyll content, ribulose bisphosphate carboxylase-oxygenase (RuBisCO), and glycine, betaine as photosynthesis and transpiration rates were unaffected. Though in general, salt stress decreases the chlorophyll and total carotenoid contents of leaves that may impact photosynthetic rate (Parida, Das, 2005).

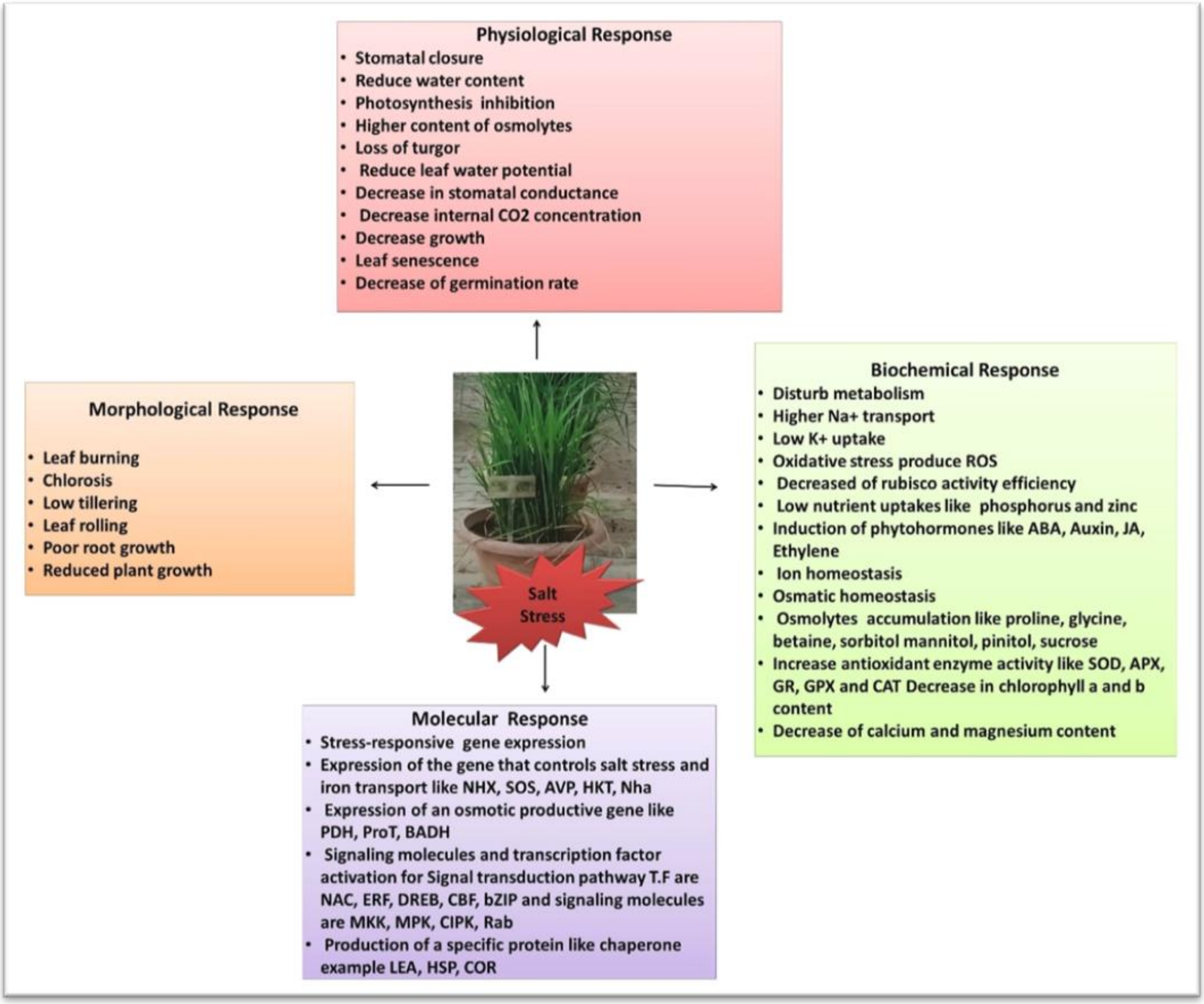

Fig.2. Overview of various types of plant response under the salt stress

During the NaCl stress in *Grevilea* plant, protochlorophyll, chlorophylls, and carotenoids have been largely reduced in comparison to Chl-a and carotenoids (Parida, Das, 2005). But on the other hand, other pigments like anthocyanin is significantly increased with increases in salt stress (Kennedy, De Fillippis, 1999). Alamgir and Ali (1999) revealed that under salt stress, leaf pigments in nine genotypes of rice were reduced in general, but relatively high pigment levels were found in other six genotypes, whereas, it was observed that some factors decreased the photosynthetic rate during the in-saline condition, i.e., high osmotic potential and reduced water availability to plants, ionic stress due to this toxicity of NaCl ions, the Cl^- ion inhibits photosynthetic rate, closure of stomata causing the reduction in CO_2 supply resulting carboxylation reaction-restriction, cytoplasmic structure and change in enzyme activities (Lyengar, Reddy, 1996; Rajput et al., 2016, 2017).

Effects of salinity on plant water relations

Water availability is the major factor in growth reduction in plants under salt stress condition but some plant grows easily with abundant water supplies even in saline environments such as mangroves (Taiz, Zeiger, 2002). Since mangroves adapted to the salt salinity of sea to obtain its water requirement and can adjust their osmotic conditions and water potential (Ψw). At water deficit conditions, plants cells can regulate their water potential (Ψw) in response to osmotic stress by lowering their solute potential ((Ψs) (Taiz, Zeiger, 2002).

The solute potential (Ψs) is decreased by two intercellular processes, first by accumulation of ions in the vacuole and second by synthesis of compatible solutes in the cytosol (Taiz, Zeiger, 2002). It can be concluded that salt stress causes osmotic stress leads to water-deficit stress, reduced water potential (Ψw) and turgor pressure in plant, that are enough to impinge on normal functions (de Oliveira et al., 2013). In water stress conditions, moderate loss of water can also leads to stomatal closure and limits exchange of gases. During low to moderate salinity and higher soil water potential, plant can maintain their water status through accumulation of compatible solutes and maintenance of influx of water and nutrient via potential gradient (Koyro, 2006; Shannon, 1997).

It was determined osmotic and ionic toxicity that caused reduction in germination of halophyte *Sueda* spp. and as salinity alleviated, germination improved and water loss controlled by regulation in transpiration or adjusting osmotic potential (Song et al., 2015). In sugar beet relative water content (RWC) decreased in salt conditions (Ghoulam et al., 2002) and decrease in RWC and loss of turgor could results in limited water availability for cell extension processes (Katerji et al., 1997). Informatirom drawn from conducted studies on salinity could led to conclusion that during higher salt concentration plant leaf cells accumulate more Na^+ and Cl^- than the normal situation. This causes lower osmotic potentials and more negative water potentials in leaf cells, reduction in root hydraulic conductance that directly influences the amount of water flow from the roots to the leaves resulting in water stress in the leaf tissues (Torabi et al., 2013).

Effects of salinity on plant ion levels and nutrient contents

Salinity stress causes double impact due to ionic toxicity and osmotic stress in plants that leads to nutritional disorder (Hasegawa et al., 2000; Zhu, 2003). In saline soil, the concentration and availability of Na^+ are higher than the concentration of K^+ (Tavakkoli et al., 2010). If NaCl concentration in the root zone of plants gets increased then Na^+ and Cl^- accumulation gets started in shoot tissue which leads to a decline in Ca^{2+}, $K^{+,}$ and Mg^{2+} levels (Bayuelo-Jimenez et al., 2003; Khan et al., 2000; Perez-Alfocea et al., 1996). When soil solution gets enriched with cations and anions then it moves towards plant cytoplasm. This movements of cations and anions are controlled by the permeability of cell membranes that contain protein transporters which facilitate the passage of ions (Jiménez-Casas, 2009). Under salt stress, salt-sensitive and salt-tolerant plants show differential responses towards K^+/Na^+ ions ratio in both root and shoot tissues (Zheng et al., 2012).

Some crops like potato showed a decrease in K^+/Na^+ ratio under salt stress that causes Na^+ toxicity leads to cellular damage whereas deficiency of K result decreases crop growth and productivity of plants (Daneshmand et al., 2009; Kibria, Hoque, 2019).

Effect of salinity on biochemical condition of plant

Salinity stress in plants causes certain biochemical changes in metabolic processes of protein, amino acid and carbohydrate. Based on the stress severity and duration, it directly inhibit the crop growth and productivity (Kibria and Hoque, 2019). Under the salt stress condition, proteins get starts accumulating that serve as a reservoir of energy or maybe adjuster of osmotic potential in plants (Ingram, Bartels, 1996; Mansour, 2000; Pessarakli, Tucker, 1985; Pessarakli, Huber, 1991). Ashraf and Harris (2004) demonstrated that some salt-tolerant cultivars of rice, barley, sunflower, finger millet have a higher amount of soluble proteins. Because of the salinity stress, soluble proteins level observed to decrease in leaves but at low to moderate salt stress concentration, soluble protein level start to increase.

Under the salt stress condition, plant accumulates various type of amino acids like proline, alanine, arginine, glycine, serine, leucine, valine and the non-protein amino acids i.e. citrulline and ornithine amides like glutamine and asparagines (Mansour, 2000). Amongst all these amino acids, proline accumulation is higher during salt stress condition in the plant cytosol due to an osmotic adjustment (Torabi et al., 2010; Abraham et al., 2003; Ketchum et al., 1991). Soluble carbohydrate in plants gets accumulated during the salt stress response and the CO_2 assimilation rate decreases significant (Murakezy et al., 2003). When glycophytes subjected to salt stress, they increase in soluble sugars up to 50% due to osmotic potential adjustments (Parvaiz, Satyawati, 2008). The building block of carbohydrates such as monosaccharides and disaccharides, i.e., glucose, fructose, sucrose, fructans and polysaccharides like starch accumulates under salt stress conditions and play a major role in osmoprotectant, osmotic adjustment, carbon storage, and radical scavenging (Parida et al., 2002).

Most prominant biochemical changes during abiotic stresses is observed, was ROS (reactive oxygen species) production (Apel et al., 2004). ROS are highly reactive agents which can cause serious disruption in metabolism through oxidative damage in cellular components like lipids, protein and nucleic acids (Arora et al., 2002). During salt stress, molecular oxygen (O_2) acts like as an electron acceptor due to which accumulation of ROS get enhanced (Gupta, Huang, 2014). ROS include singlet oxygen ($^1O_2^*$), hydroxyl radical (OH^-), superoxide radical(O_2^-), and hydrogen peroxide (H_2O_2) are all strong oxidizing compounds that can damage the biological membranes of cell and cell organelles (Santos et al., 2018).

Overview of salt stress signaling

When plants are subjected to the salt stress conditions then the salt stress sensing signaling pathway gets activated and the $Ca^{2+}{}_{cyto}$ amount heightened that acts as a secondary messenger and initiates a series of reactions or signaling cascade. This signaling cascades modifes the expression of several genes responsive to salt stress. This signaling cascade also knows as salt stress signal transduction pathway is a complex mechanism that involves proteins, lipids, hormones, metabolites, Ca^{2+} and ROS.

This salt signal transduction pathway has mechanism constitutes of (i) SOS pathway; (ii) mitogenic activated protein kinases (MAPK) cascade; (iii) phospholipid dependent; (iv) phosphoprotein cascade; (v) calcium/ calmodulin-dependent; (vi) H_2O_2 activated; and (vii) acid abscisic (ABA) dependent (Taiz, Zeiger, 2002; Conde et al., 2011; Peng et al., 2014; Shinozaki et al., 2015).

(1) Osmotic signal transduction

Osmotic signal transduction-triggered genes are mainly regulated by ABA phytohormones, but not applicable for all osmotic genes that are involved in salt stress. It is regulated by ABA-dependent or independent regulatory pathway. Both these two signalling pathways are activated by the transcription factors that interact with the promoter region of specific salt induced responsive genes resulting in up or down-regulation of their expression (Figure 3).

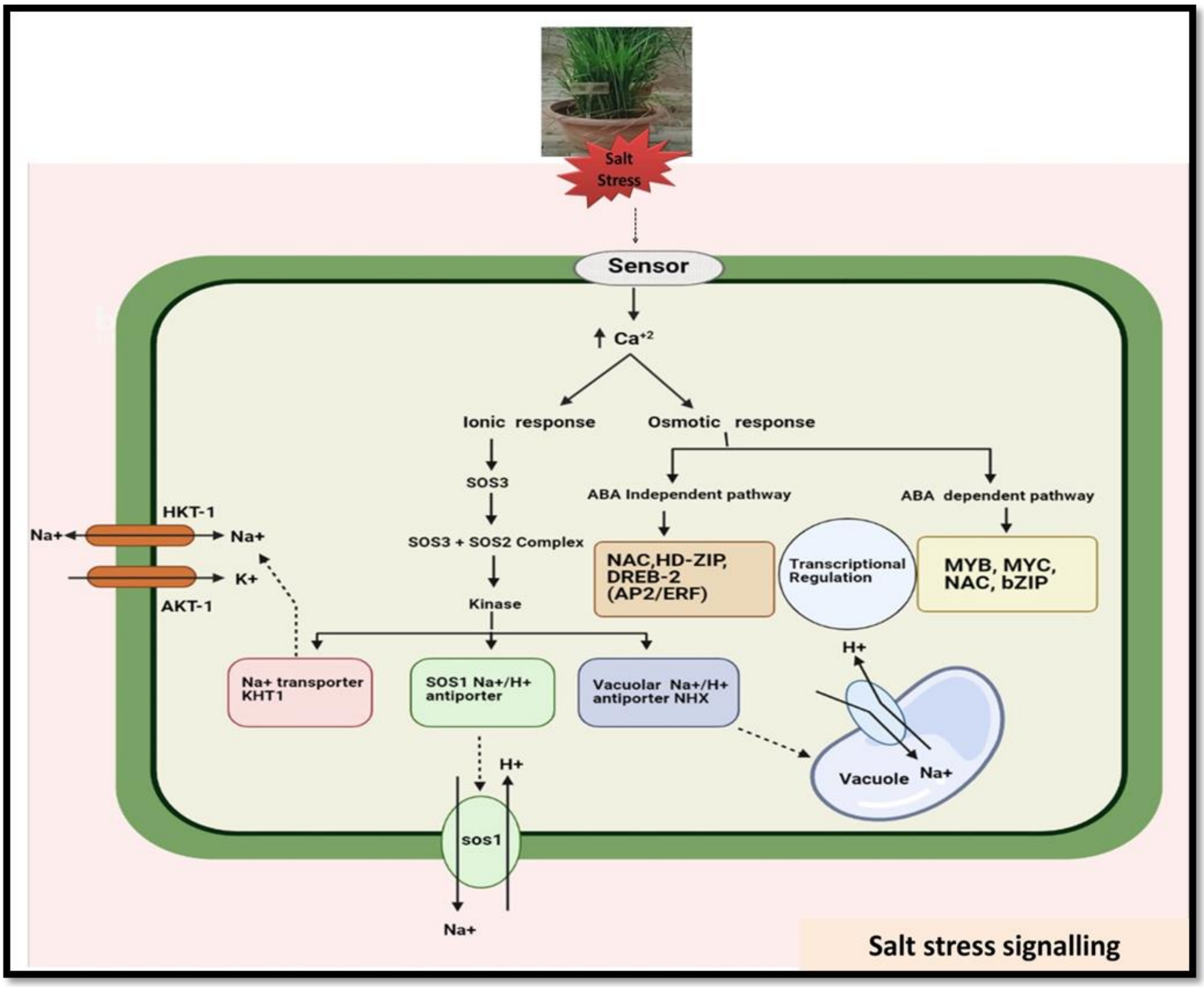

Fig. 3. Diagrammatic representation of salt stress signalling

(A) ABA-dependent signaling pathway

During the salt stress, ABA-dependent signalling pathway has ABA-regulated gene promoters that have six nucleotide sequence elements known as ABRE (ABA-responsive element). ABRE element is cis-acting regulatory protein that is required for expression and function of its own gene and also other cis-acting elements.

Under salinity stress, the lots of ABA signalling cascades functions., e.g., upstream of basic leucine zipper (bZIP) transcription factors, PYR1/PYLs/ RCARs receptors, PP2C phosphatases, and SnRK2 protein kinases (Shinozaki et al., 2015).

(B) ABA-independent signaling pathway

In the ABA-independent signalling pathway, osmotic stress-responsive genes are regulated by two signalling pathways. In one pathway, DREBP/CBF transcription factors binds to DRE (dehydration-responsive element)) elements in the promoter of osmotic stress-responsive gene and activates its function whereas in second pathway, ABA-independent osmotic stress-responsive genes are directly controlled by the MAP kinase signaling cascade of protein kinases or MAPK signaling pathway (Taiz and Zeiger, 2002).

(2) Ionic signal transduction

Ionic signal transduction pathways are involved in ion homeostasis that has been first characterized in Arabidopsis through the studies on mutant plants that are excessively sensitive to salt (SOS mutant). Early response to salt stress increased calcium (Ca^{2+}) level and this increment of calcium was attached by the calcium-binding protein SOS3 and undergoes conformation changes that facilitate its interaction with the kinase SOS2 a serine/threonine protein kinase.

The SOS2 have negative regulatory domain but its interaction with SOS3 leads the negative domain get autoinhibited and results in induced kinase activity. The SOS2 have a specific role in adaptation to high sodium and low potassium stress. The SOS3-SOS2 complex get phosphorylates and activates SOS1.SOS1 is a type of Na^+/H^+ antiporter of the plasma membrane of plant cell. Higher activity of SOS1 decreased the level of cytosolic Na^+ in saline conditions.

Morden crop improvement technology for development of salt resistance crops

Soil salinity is a major constraint to agriculture crop production, food and feed.

Various traits such as ion exclusion, osmotic tolerance and tissue tolerance can be integrated to improve salinity tolerance in crops. Several approaches has been made to improve salinity tolerance in crops such as genetic engineering, nanoparticales mediated crop improvements and marker assisted breeding.

Modern biotechnological methods (marker-assisted selection or genetic engineering) needs to be progressively exploited for introduction of the correct combination of genes into elite crop cultivars. In modern biotechnological methods, genetic engineering has been recognized as a revolutionary technique for generation of salt tolerant plants as one can transfer desired gene from any genetic resource to another and can alter the expression of existing gene(s) (Singh et al., 2021). Through the use of genetic engineering various crops have improved salinity tolerance (Nongpiur et al., 2016). Molecular markers associated with genes or quantitative trait loci (QTLs) affecting important traits are identified, and could be used as indirect selection criteria to improve breeding efficacy through marker-assisted selection (MAS). Numerous QTLs have been reported for salt tolerance in different crop species, however, MAS has been used in few commercial cultivars or breeding lines to improve salinity tolerance (Ashraf et al., 2012). Nanoparticles application has been found to be promising technique in agriculture to augment crop productivity under normal and harsh environmental conditions such as salt stress (Khan et al., 2020). Various evidences (Zulfiqar et al., 2021) have suggested that supplementation of nanoparticles to plants can significantly reduce the injurious effects caused by numerous harsh conditions including salt stress, and therefore can regulate adaptive mechanisms in plants. Various types of nanoparticles and nanofertilizers have shown a promising evidence regarding salt stress management.

In this section, the latest progress have made towards obtaining salt stress tolerance in crop plants utilizing genetic engineering, molecular marker and nanoparticles are explained.

Genetic engineering

Genetic engineering has been in the major attention of crop improvement for decades. This is mostly due to the several debates has been made up by the first generation of genetically engineered/genetically modified (GM). Transgenic plants displayed enhanced tolerance for high salt concentration and extreme temperature by expressing bacterial choline-oxidizing enzymes

(Sakamoto, Murata, 2001). Tarczynski et al. (1993) introduced a bacterial gene that encodes mannitol 1-phosphate dehydrogenase into tobacco plants, resulting in mannitol accumulation and enhanced tolerance to salinity. Transgenic tobacco plants carrying a cDNA encoding myo-inositol O-methyltransferase (IMT1) resulted in accumulation of D-ononitol, enhanced photosynthetic protection and enhanced recovery under drought and salt stress (Sheveleva et al., 1997).

SOS 1 gene in *A. thaliana* encode for plasma membrane Na^+/H^+ antiporter, was reported to be essential for salt tolerance (Shi et al., 2002) and recently Shi et al. (2003) stated that overexpression of SOS1 improves salt tolerance in transgenic *Arabidopsis*. Xu et al. (1996) described that the expression of HVA1, an LEA III family protein in barley, confers tolerance to water deficiency and salt stress in transgenic rice plants. Recently, biochemical analysis validated that SP1, which is a stress responsive gene and member of a novel protein family functions as a molecular chaperone in protecting and repairing various heat-labile enzymes (Wang et al., 2001, 2002b).

Preliminary results reported that elevated expression of SP1 have correlation with salt-stress tolerance (Wang et al., 2003; Barak, 2003). Lately, transgenic tobacco that were transformed with the animal cell death suppressors Bcl-xL and Ced-9 resulted in enhanced resistance to various stresses such as UV-B, paraquat, salt, cold and wounding stress (Mitsuhara et al., 1999; Qiao et al., 2002). Transgenic tobacco seedlings, grew significantly faster than control seedlings that were exposed to chilling or salt stress which were overexpressing cDNA which encodes an enzyme with both glutathione S-transferase (GST) and glutathione peroxidase (GPX) activity (Roxas et al., 1997). Transgenic tobacco (*Nicotiana tabacum*) overexpressing the p5cs gene that encodes P5CS produced 10- to 18-fold more proline showed better performance under salt stress (Kishor et al., 1995) because P5CS have role of rate-limiting enzyme in proline biosynthesis in plants, and is subject to feedback inhibition by proline, thus removal of the feedback inhibition can lead into a high level of proline accumulation in plants (Hong et al., 2000).

Transgenic plants overexpressing ADC (arginine decarboxylase) gene showed an increase in biomass and better performance toward salt stress conditions (Wang et al., 2011). In different conditions of environmental stresses there is the accumulation of LEA proteins, including several groups of high molecular weight proteins. It has been reported that plants expressing a wheat LEA group 2 protein (PMA80) and group 2 protein gene (PMA1959) resulted in increased tolerance to dehydration and salt stresses (Amudha et al., 2011). Transcription factors (TFs) exhibit higher correlation with salinity have roles in regulation and modification of different stress-responsive genes such as AP2/ERF, bZIP, NAC, MYB and WRKY inhibitor (Kumar et al., 2017).

Recently, it has been reported that the HDAC (histone deacetylase) inhibitor, suberoylanilide hydroxamic acid (SAHA) have role in enhancing tolerance to high salinity in cassava (Patanun et al., 2017). NHX genes from wheat have potential role in conferring salinity tolerance in Arabidopsis, tobacco, vegetable, and legume forage crops through the approach of genetic engineering (Yarra, 2019). Saxena (2020) repoted that Cytosolic ascorbate peroxidase (Apx1) gene that was isolated from *Arabidopsis thaliana*, selected as the candidate gene for strengthening the antioxidative defense system of *Brassica juncea*. The transgenic plants performed well as compared to their non-transgenics under saline condition, exposed through greater proline accumulation, increased chlorophyll stability index, lower chlorophyll a/b ratio, and higher antioxidative enzyme activities.

Nanoparticles mediated crop improvement for salinity tolerance

Accumulation of excessive salt contents in the soil can inhibit plant growth and decreased crop production directly or indirectly. Salinity stress causes negative impact on the plants growth through the ROS generation and increased osmotic stress. Similarly, lowering of leaf water potential leads physiological and morphological changes and ion toxicity alters the biochemical processes (Rajput et al., 2015).

Recently, various nanoparticles are used for development of salt tolerance crops such as C, K, Ca, S, Ag, Cu, Fe, Zn, B, Si, Ti, and many others (Avestan et al., 2019; Abdoli et al., 2020; Alabdallah, Alzahrani, 2020; Khan et al., 2020; Ye et al., 2020). Zinc is supposed to have played various vital roles in plants particularly salinity stress (Sofy et al., 2020). Farouk and Al-Amri (2020) reported that Zn-NPs application to salt stressed canola (*Brassica napus*) plants upregulated the antioxidant system, osmolyte biosynthesis, and ionic regulation to lessen the harmful effects of salinity. The Ag NPs identified for modulating numerous physio-biochemical traits in plants to improve multiple growth related features comprising germination and growth even under harsh condition including salinity (Soliman et al., 2020; Mohamed et al., 2017). Khan et al. (2020) reported that oxidative damage was reduced under saline condition when seeds of *Pennisetum glaucum* were primed with Ag nanoparticals due to enhanced antioxidant enzyme activities. Moreover, Ag nanoparticals suppressed Na^+/K^+ ratio thus increased flavonoids and phenolic contents in leaves (Khan et al., 2020). Mohamed et al. (2017) reported that when wheat seeds were treated with Ag nanoparticals before sowing showed improved growth, proline, soluble sugars, and peroxidase activity even in salt stress condition.

Silicon is not an integral plant nutrient but various reports have showed that application of Si can improve improved photosynthesis, vegetative growth, and dry matter production, as well as decreased shoot Na^+ and Cl^- deposition and improved K^+ accumulation under salt stress condition (Javaid et al., 2019; Abdelaal et al., 2020; Hurtado et al., 2020). Mushtaq et al. (2019) reported that treatment of nano-SiO_2 resulted in enhanced seed germination and growth on salt stressed wheat cultivars by improving leaf K^+ concentration, and levels/activities of biological antioxidants (Farhangi-Abriz, Torabian, 2018).

Copper metal-based micronutrient that influences numerous vital metabolic reactions in plants and can mediate photosynthesis in plants (Yamasaki et al., 2008). In tomato plants, application of Cu nanoparticals improves the growth performance and Na^+/K^+ ratio under salt stress condition (P´erez-Labrada, Lopez-Vargas, 2019). Hernandez-H et al. (2018) suggested that the application of Cu nanoparticles can enhance salt tolerance by activating the antioxidant defense mechanism and by the octadecanoid pathway of jasmonates. The effect of Fe_2O_3 nanoparticle on *Dracocephalum moldavica* plants showed enhanced growth and enzymatic activites under salinity stress (Moradbeygi et al., 2020). Abdoli et al. (2020) examined that the combined treatment of Fe_2O_3 nanoparticles alleviated salt stress via improving K^+/Na^+ ratio, Fe content, the activities of antioxidant machinery (SOD, CAT, POD, and polyphenol oxidase), endogenous salicylic acid, and some key osmolytes in *Trachyspermum ammi*.

Manganese is a crucial component of vital plant processes (Ye et al., 2019). *Vigna radiata* plants is reported to improve membrane stability index, chlorophyll content, and nitrate reductase activity under salt stress condition (Shahi, Srivastava, 2018). Application of Mn caused recovery from chlorosis and restricted growth due to saline stress in rice seedlings (Rahman et al., 2016). Application of carbon nanomaterials (CNMs) in agriculture has shown typical potential towards improving crop yield under nonstress and stress condition (Martínez-Ballesta et al., 2016; Baz et al., 2020). Nanoparticles (NPs) can alleviate unfavorable environmental conditions in plants predominantly salinity stress (Khan et al., 2017). Supplementation of multi-walled carbon nanotubes (MWCNTs) resulted in improved rate of photosynthesis and water uptake in broccoli under salt stress (Martínez-Ballesta et al., 2016). MWCNTs were reported to mediate salinity stress by improving aquaporin transduction, which resulted in enhanced water uptake (Martínez-Ballesta et al., 2016). Zhao et al. (2019) reported increase in nitrate reductase dependent NO biosynthesis, re-establishment of ion and redox imbalance demonstrated by the decrease in ROS overgeneration, reduction in thiobarbituric acid production, and decrease in Na^+/K^+. He also provided molecular evidence of induced alteration in Na^+/H^+ exchanger 1 (NHX1) and K^+ transporter 1 (KT1) transcripts, antioxidant defense system genes, and salt overly sensitive 1 (SOS1) genes when treated with MWCNTs.

Spray of carbon nanohorns (CNHs) on *Sophora alopecuroides* seedlings showed improved the root fresh weight, leaf soluble sugar content, leaf and root total protein contents, leaf PSII activity and Cu contents (Wan et al., 2020). Through pyrolysis process of bioenergy and agricultural feedstocks, carbonaceous material generated that is Biochar (Lehmann et al., 2007). Spectroscopic analysis proved enhancement of soil P absorption when Mahmoud et al. (2020b) applied nanobiochar. Titanium dioxide (TiO_2) NPs can alter enzyme acivities and improve chlorophyll pigments and photosynthesis in plant (Carbajal-VaZquez´ et al., 2020). Recently, it was shown improved growth and increase in activities of some key enzymes when they were treated with TiO_2 on *Dracocephalum moldavica* plants under salinity stress (Gohari et al., 2020a, 2020b). TiO_2 NPs in lowest concentration (0.01 %) can reinforce salt tolerance via enhancing enzymatic activities, amino acids, soluble sugars, and proline (Abdel Latef et al., 2018).

Under normal growth conditions Ce nanoparticles at low conentration can influence physio-biochemical characteristics in plants (Salehi et al., 2018). Abbas et al. (2020) reported that low levels of Ce NPs can enhance growth and photosynthesids in wheat. Potassium is vital for growth, metabolism, and unfavorable stress alleviation in plants (Jan et al., 2017). When crop plants were applied K exogenously under normal (non-stress) or stress conditions showed benefitted widely (Hatam et al., 2020; Xu et al., 2020). El-Sharkawy et al. (2017) reported the role of K_2SO_4 NPs on *Medicago sativa* L under salt stress condition alterd the physiological characteristics via lowering the electrolyte leakage thus improved antioxidant enzymes and osmoprotectants activities.

Sulfur has been demonstrated as a necessary element for the growth and development processes of crop plants. Najafi et al. (2020) reported the effect of green synthesized sulfur nanoparticles on lettuce and reported enhanced osmoprotectants, total phenols, soluble sugars, flavonoids, anthocyanins, and tannin. The research on role of sulfur NPs under salt stress is rare and therefore, future studies should focus on application of sulfur NPs on salt stressed plants.

Marker-assisted breeding

In recent decades, DNA marker technology has reformed the genome research and breeding. Application of various available molecular markers and QTL mapping techniques that have contribution in various agronomically important traits such as resistance to biotic stresses, abiotic stresses tolerance, yield and nutritional quality in various crops (Xue et al., 2010; Ali et al., 2013) for the good knowledge of genetic bases of these stress related traits. A few salt stress related QTL detected by various molecular markers have been discussed in this section. Kna1 has been reported in hexaploid bread wheat (*Triticum aestivum*) that regulate the transport of Na^+/K^+ from root to shoot precisely, by comprising a lower Na^+/K^+ ratio within the leaves (Gorham et al., 1987, 1990; Luo et al., 1996). In durum *Triticum turgidum* L. ssp. durum Desf. (wheat) discharge process of Na^+ is associated to *Nax1* (Na+ exclusion 1; Huang et al., 2006, 2008), that might be related to the HKT8 (HKT1;5) and HKT7 (Na^+ transporters HKT1;4). It has been reported that *Nax1* loci efficiently reduce Na^+ passage to shoot from root, by keeping Na^+/K^+ balance by loading K^+ into and excluding Na+ from, the xylem within the leaf of wheat plant (James et al., 2006). Yao et al. (2006) have identified two QTLs for root Na^+/K^+ ratio that were mapped to chromosomes 2 and 6 by using F2 population of a hybrid within indica rice cultivar 'IR36' and japonica rice cultivar 'Jiucaiqing' . In rice different QTLs have been recognized for Salt tolerance which include those at chromosome number 1- *Saltol* QTL, *QNa*, and *SKC1/OsHKT8* along with, QNa:K on chromosome 4. *Saltol* states many changes for the uptake of ion during salinity stress (Bonilla et al., 2002; Gregorio et al., 2002). For highest Na+ uptake *QNa* is QTL (Flowers et al., 2000) and for Na^+/K^+, QNa:K is the corresponding QTL (Singh et al., 2001). *SKC1/OsHKT8* is the resultant QTL for K^+/Na^+ ratio regulation for homoeostasis in salt stress tolerant indica cultivar 'Nona Bokra' (Lin et al., 2004; Ren et al., 2005). Many other QTLs are identified in the root for Na^+/K^+ ratio except chromosome 9 and for exchange of ion three QTLs on chromosomes 10 and 3 (Sabouri and Sabouri, 2008), for tissue Na^+/K^+ ratio four QTLs and each for Na^+ and K^+ uptake on various chromosomes one QTL (Lang et al., 2001). Consequently, 14 QTLs has been identified for shoot and root Na^+/K^+ ratio and Na^+ and K^+ content on different rice chromosomes (Ahmadi, Fotokian, 2011).

The *QKr1.2* was identified as one of the major QTL on chromosome 1 for root K^+ content, that explained around 30% of the variation of observed salt stress tolerance in rice. Moreover, two newly identified QTLs (*SalTol*8-1 and *SalTol*10-1) on chromosome 8 and 10 based on an F2 hybrid of a cross between a high salt stress tolerant line (IR61920-3B-22-2-1) and a medium salt stress tolerant line BRRI- dhan40 (Islam et al., 2011). Many studies have revealed QTLs for salt stress tolerance related phenotypes in *Hordeum vulgare L.* (barley). Lately, 30 QTLs were identified for 10 different traits, such as K^+ and shoot Na^+ content, yield-related traits, several growth and Na^+/K^+ ratio, in populations grown on normal soil and saline soil. In the three species of *Helianthus sp.* (sunflower) and *Helianthus paradoxus* ,fourteen ion uptake QTLs were identified for QTL analysis from highly salt affected habitat and its salt sensitive ancestor *H. petiolaris* and *H. annuus* (Lexer et al., 2003).

Huyen et al. (2013) developed new rice lines with salinity tolerance and high yield by applying markers assisted selection (MAS). Q5DB/FL478 were investigated to evaluate the introgression of Saltol fragment into Q5DB cultivar and developed salt tolerant rice with high yield. In one of the study (D Leon TB et al., 2017), introgression lines (ILs) of a salt tolerant donor line 'Pokkali' developed in a susceptible high yielding rice cultivar 'Bengal' background was evaluated for numerous morphological and physiological traits under salt stress. Both SSR and genotyping-by-sequencing (GBS) derived SNP markers were employed to characterize the ILs and identify QTLs for salinity tolerance trait. In recent study various efforts have been made to generate NILs of a popular rice genotype 'Improved White Ponni' displaying increased tolerance against salinity through marker assisted introgression of 'Saltol', which is a major QTL of FL478. IWP-*Satol* NILs exhibited enhanced tolerance against salinity under hydroponic conditions (Valarmathi et al., 2019).

Lately, Muthu et al. (2020) developed abiotic stress-tolerant rice genotypes in the genetic background of the popular rice variety Improved White Ponni (IWP) through a marker assisted backcross breeding approach by introgressing major effect quantitative trait loci (QTLs) conferring tolerance against drought ($qDTY_{1.1}$, $qDTY_{2.1}$), salinity (*Saltol*), and submergence (*Sub1*). Additional studies are required to decide the benefits of unreported QTLs for crop breeding to improve salt stress tolerance. As molecular marker techniques for breeding is economical and rapid. This technique is a very powerful method to enhance breeding programs to improve plant tolerance toward salinity.

Pond soil culture technology

In rural areas where there is a sodic-saline land for farming on these land, rural farmers use a method in which they use the dry fertile soil of the ponds and put it on sodic-saline land at a certain level, which makes that land fertile. Scientifically observed, the same amount of micros are found in the soil of the ponds, which make the soil of the pond more fertile and when these microbes reach the sodic-saline land slowly these lands are also made fertile, by which this land is ready to grow different crops (Figure 4).

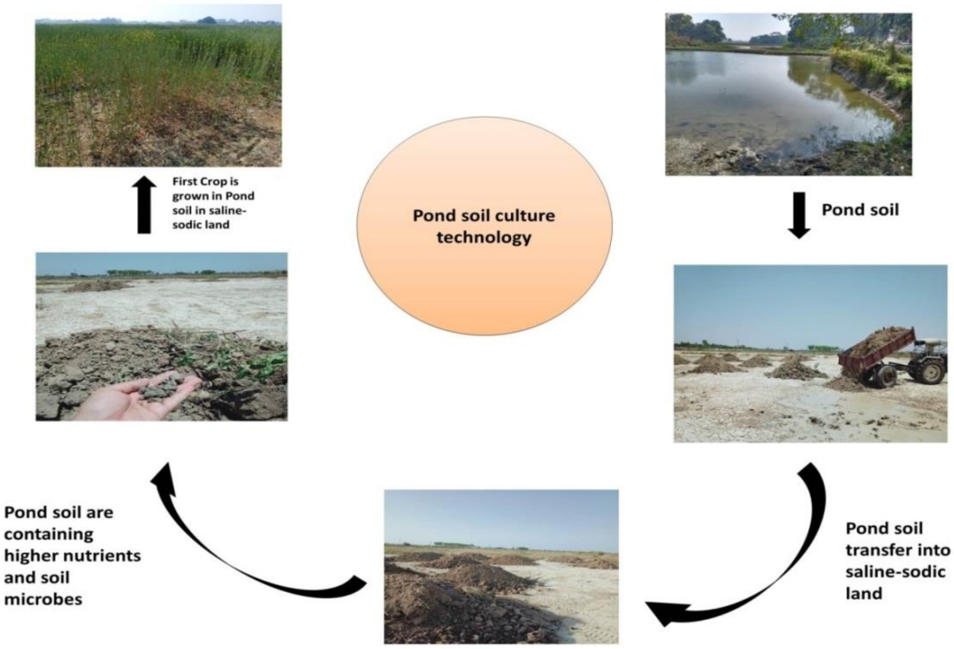

Fig. 4. Pond soil culture technology which mostly uses in East Uttar Pradesh where land is saline-sodic, these photographs are taken from a village of east Uttar Pradesh Machhlishahr of Jaunpur district name Pauha, India where this technology is used by progressive farmers

3. Conclusion

Soil salinity poses a serious threat to food security worldwide. To meet with food requirement of the ever-increasing population and shrinkage of cultivable land due to industrialization and urbanization has put the onus on the scientific community to develop sustainable agriculture practices and enhance food production, restore salt-affected soils, and its management through government policymaking, and contribution from all stakeholder provide potential hope of land expansion and production enhancement for future food security. Agricultural intensification through various methods like nanoparticles-based agro-practices, genetic engineering, development of salt stress plants deemed indispensable and possibly leading to increased food production per unit area that paves the way to achieve food sustainability.

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